

DEVELOPING EFFECTIVE AND QUANTIFIABLE AIR QUALITY MITIGATION MEASURES: OVERVIEW REPORT

U.C. Davis-Caltrans Air Quality Project

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Abstract

Background: Caltrans sought air quality mitigation information applicable to the environmental evaluation of transportation projects, especially mitigation measures that focus on particulate matter (PM) originating from diesel exhaust.

Methods: In this study we examined mitigation measures as a means for reducing diesel PM emissions from transportation project operations, based on extensive literature reviews and assessments and case studies. Specifically, we reviewed vehicle-related engineering design parameters associated with diesel PM emissions at the transportation-project level, and assessed near-road air pollution issues through a meta-analysis of measured air pollutant concentrations near roadways. Potential mitigation measures at both regional- and project scales were identified with their applicability and cost-effectiveness. Two case studies were also conducted; they focused on mitigation related to goods movement (heavy-duty truck rerouting near a port) and normal freeway operation (vegetation barriers near roadways).

Results: Our research efforts resulted in five major reports: (1) Project-Level Mitigation: What Affects Diesel Particulate Matter Emissions, (2) Near Roadway Air Quality: A Meta-Analysis, (3) A Review of On-Road Vehicle, Mitigation Measures, (4) Mitigating Diesel Truck Impacts in Environmental Justice Communities: Transportation Planning and Air Quality in Barrio Logan, San Diego, and (5) Practical Mitigation Measures for Diesel Particulate Matter: Near-Road Vegetation Barriers.

About The U.C. Davis-Caltrans Air Quality Project

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Mission: The Air Quality Project (AQP) seeks to advance understanding of transportation related air quality problems, develop advanced modeling and analysis capability within the transportation and air quality planning community, and foster collaboration among agencies to improve mobility and achieve air quality goals.

History: Since the 1990s, the U.S. Federal Highway Administration and Caltrans have funded the AQP to provide transportation-related air quality support. Caltrans and AQP researchers identify and resolve issues that could slow clean air progress and transportation improvements.

Accessibility: AQP written materials and software tools are distributed through our website, peer-reviewed publications, conference presentations, training classes, formal reports and technical memoranda, and periodic newsletters.

Research: AQP investigations focus on project-level, regional-scale, and national-level assessments. Tools and publication topics cover pollutant-specific problems such as those involving particulate matter, carbon monoxide, carbon dioxide, ozone and air toxics; activity data collection and assessment for on- and off-road vehicles and equipment; mitigation options such as transportation control measures; policy analyses addressing transportation conformity and state implementation plan development; litigation support; and goods movement assessments.

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Introduction

Over the past several years, the environmental evaluation of transportation projects has been extended from the traditional focus on carbon monoxide (CO) to include particulate matter less than 10 and 2.5 micrometers in diameter (PM₁₀ and PM_{2.5}) and mobile source air toxics (MSATs). There is ongoing concern about the relatively high pollutant concentrations – and resulting exposures – observed in close proximity to heavily traveled freeways and arterials. In particular, addressing diesel particulate matter (DPM) emissions has become an issue of increasing interest, given that DPM has been identified as the single most important toxic air contaminant in urban California settings (California Air Resources Board, 2008; South Coast Air Quality Management District, 2008). Caltrans is therefore seeking mitigation information for transportation projects, especially control measures related to PM originating from diesel exhaust.

The purpose of this work has been to examine potential mitigation measures as a means for reducing DPM emissions from transportation project operations. The results are meant to inform Caltrans project analysts and help identify opportunities to implement feasible mitigation measures that reduce environmental impacts as well as improve project delivery. Based on the latest existing information in the transportation-related air quality literature as well as emissions modeling, this study reviewed a wide range of potential mitigation options and linked their benefits to project-specific parameters. Both qualitative and quantitative analyses of practical mitigation measures for DPM along with specific case studies were conducted to help project planners understand mitigation opportunities. In addition, this study also included a meta-analysis regarding near-road air quality issues; its outcomes provide project analysts the tools to improve the environmental assessment of proposed projects.

As shown in Figure 1, five studies were carried out to construct an integrated analysis package that addressed mitigation-related issues from different perspectives: 1) an examination of vehicle-related engineering design parameters that are associated with PM emissions at the transportation-project level; 2) a meta-analysis of the spatial and temporal impact of vehicle traffic emissions on near-road air quality; 3) a general review of regional- and project-scale vehicle emissions control measures; 4) a goods movement-related case study of mitigating diesel truck impacts for environmental justice communities through truck rerouting in Barrio Logan, San Diego of California; and 5) a pilot assessment of near-road vegetation as a mitigation measure to address normal freeway operations.

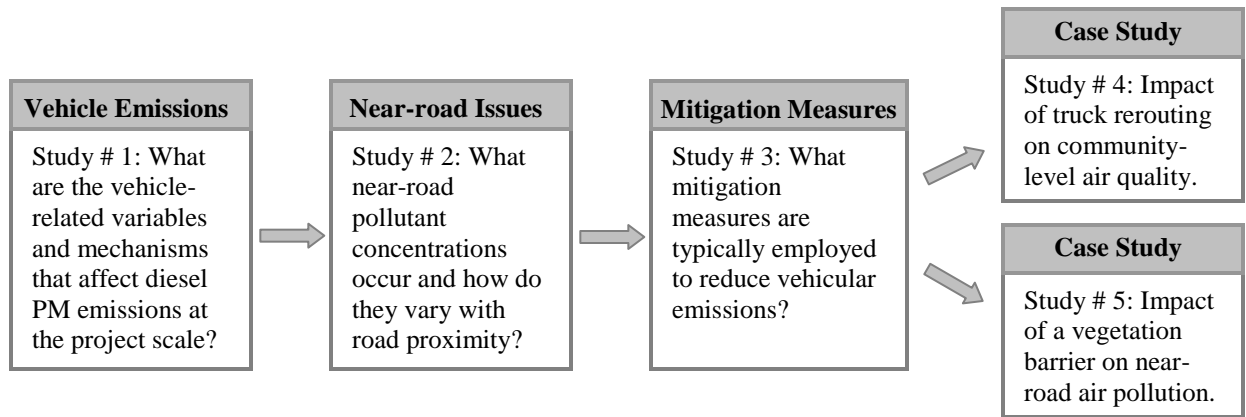


Figure 1. Five studies included in the integrated mitigation-related analysis package.

Project-level Mitigation: What Affects Diesel Particulate Matter Emissions

In order to develop effective DPM mitigation measures, it is necessary to understand vehicle-related engineering design parameters that are associated with DPM emissions at the transportation-project scale. Almost all of the PM emitted from diesel vehicles is PM_{2.5} (particulate matter less than 2.5 micrometers in diameter). This study (Van Houtte et al., 2008) aimed at understanding the important variables that affect mass emissions of PM_{2.5} from diesel vehicles and identifying the implications of these variables for the development of project-specific mitigation measures.

Existing literature suggests three categories of parameters that affect DPM emissions: vehicle characteristics (e.g., engine type, engine size, and exhaust-treatment technology), fuel composition (e.g., fuel formulation and sulfur content), and vehicle operational parameters. For project-level mitigation, vehicle operational parameters are more related, while vehicle characteristics and fuel composition are typically beyond the control of a local project. In particular, the effect of operational parameters on DPM emissions were mainly measured based on standardized drive cycle tests using simulated road loading and real-world traffic tests. This work reviewed a range of studies with respect to both tests. Example approaches reviewed included CO-binning studies using a carbon monoxide time trace to infer conclusions about DPM emissions, time resolved studies that measured second-by-second DPM emissions, as well as roadside studies that validated theoretical emissions and dispersion models with ambient measurements.

This review indicated that DPM emissions correlate well with cold start, load, acceleration, and transient engine operation (e.g., stop-and-go and variable acceleration and deceleration activity). The dominant operational parameters influencing DPM emissions are transient operation and engine load. Power-based parameters (e.g., aggressive acceleration and intensity) and time-based parameters (e.g., idle time) typically suggested a positive correlation with emissions where measurable. In contrast, average speed appeared to be an uncertain parameter, showing a negative or a nonlinear u-shaped correlation with DPM emissions.

Accordingly, some examples of practical transportation project design approaches to reduce DPM emissions include:

- improving traffic flow;
- reducing the number of starts and stops;
- reducing number and slope of uphill grades;
- enforcing speed limits;
- imposing weight restrictions;
- limiting multiple trailers; and
- applying parking restrictions.

Existing research has indicated that a number of project-specific parameters can be adjusted to reduce DPM emissions, but large variations still exist in quantitative data measurements due to the limited number of vehicles tested. Further research is needed to confirm and build upon the findings to date. Further research is needed to examine the impact of different parameters on DPM emissions based on larger test vehicle sets and consideration of vehicle fleet changes.

Air Pollution Near Roads: A Meta-analysis

A direct impact of vehicle emissions is near roadway air pollution, the concern over which has motivated much of the work for this research program. Few resources are available to comprehensively assess what is known regarding the relationship between distance from heavily-traveled roads and pollution concentration gradients. We therefore prepared this assessment to characterize near roadway pollutant concentrations and improve understanding of where the largest gains can be made by mitigation strategies at the transportation project level.

This work (Karner et al., 2009) created and then assessed a large dataset to synthesize data from the literature on near roadway air pollution, and to determine what is known about the atmospheric transport and fate of air pollution, as emitted from vehicles on a roadway and carried downwind, eventually reaching background concentrations. Based on more than thirty studies from the peer-reviewed literature, the compiled database included hundreds of measurements of pollutant concentrations and their associated distances from the road, with the majority of observations taken within 150 meters of the roadway.

Normalizing observed concentrations to both background and edge-of-road concentrations, local regression models were specified to the concentration-distance relationship and analysis of variance was used to determine statistical significance of trends. Based on edge-of-road normalization, most pollutants decay to background by 80 – 600 m from the edge of road; based on background normalization, most pollutants decay to background by 160 – 800 m from the edge of road. For pollutants where both techniques estimated distance-to-background, edge normalization estimated a shorter distance-to-background in approximately 70 percent of cases. Differences arose largely due to the different approaches used to estimate background concentrations across the various studies investigated.

This work provides insights regarding the design of mitigation strategies directed at certain pollutants. For example, efforts directed further than 400 m from the road are likely to produce

diminished results compared to those located closer to the edge. Several factors were shown to consistently influence observed concentrations, such as wind speed and direction, traffic volumes, and fleet composition. Future research could use the dataset assembled for this work to further assess the magnitude and relative contribution of each factor to observed concentrations, and then connect roadside pollution analyses with implementation of mitigation measures.

A Review of On-road Vehicle Mitigation Measures

Mitigation measures, or vehicle control measures, typically refer to programs or strategies designed to reduce vehicular emissions for a particular region or area, and are necessary for the development of State Implementation Plans (SIPs) to improve air quality. There has been ongoing interest in evaluating on-road vehicle mitigation measures, which can reduce mobile source emissions either directly (e.g., by tightening emissions standards, retrofitting, and introducing fuel reformulations) or indirectly (e.g., by relieving traffic congestion, encouraging rideshare, and shifting private auto use to non-auto travel modes).

This study carried out a literature review that aimed at understanding the applicability and cost-effectiveness of both regional- and project-scale mitigation measures. In addition to focusing on control strategies applicable to carbon monoxide (CO), nitrogen oxides (NO_x), and hydrocarbon (HC), the assessment in this review placed special emphasis on DPM. Regional-scale mitigation measures covered in this review included fleet retirement and replacement programs, retrofitting, inspection and maintenance (I/M) programs, and use of reformulated or alternative fuels. Project-scale mitigation measures included Transportation System Management (TSM), Transportation Demand Management (TDM), and special project-level diesel control measures.

Regional-scale mitigation measures were found generally effective, but each measure showed disadvantages as well as advantages, and the cost-effectiveness of different measures varied widely (e.g., ranging from about \$3,000 to \$32,000 in 2006 dollars per ton of PM reduction). For CO, NO_x, and HC, improving I/M programs seemed to be the most cost-effective measure and were commonly listed as a core control measure for urban areas; however, I/M programs are not directly applicable to PM emissions. Other key findings include:

- Benefits of new-vehicle/engine emission standards take many years to accrue given the long life of the on-road diesel vehicle fleet; vehicle scrappage/retirement programs can be implemented to remove older high emitters. The potential benefits associated with scrappage/retirement efforts will likely decrease over time as the fleet turns over.
- Diesel retrofits can significantly reduce PM emissions; two popular retrofit technologies were diesel particulate filters (DPFs) and diesel oxidation catalysts (DOCs), which could typically reduce PM emissions by 80-95% and 20-50%, respectively.
- I/M programs may reduce emissions for CO, NO_x, and HC by as much as 35%, but the benefits may be heavily dependent upon the type of station conducting inspections; relatively little information is available to document the potential PM emission reduction benefits associated with I/M.

- Replacing current fleets with alternative fueled vehicles could be effective, but benefits tended to hinge on the availability of new fueling facilities and other factors.

Project-level mitigation measures in the reviewed literature mainly fell into three groups: improving traffic operations to smooth traffic (e.g., through HOV lanes, efficient traffic signalization, and accident avoidance measures), changing driving behaviors to reduce automobile use (e.g., through employer-based programs, public education and outreach programs, bicycle/pedestrian programs, public transit, and parking control/management), and reducing diesel exposure in sensitive areas (e.g., through truck idling control and re-routing). In general, traffic flow improvements that reduce stop-and-go driving appeared to be more effective than TDM, and had the added benefit of helping reduce all emissions of concern, including DPM.

Mitigating Diesel Truck Impacts in Environmental Justice Communities: Transportation Planning and Air Quality in Barrio Logan, San Diego

Real-world case studies are important for assessing the performance and impact of a particular mitigation measure applied in practice. This case study described and assessed the impacts of traffic operational improvements implemented to mitigate pollution impacts in Barrio Logan.

Barrio Logan is a neighborhood of San Diego, California and is recognized by government agencies as an ‘environmental justice’ community. Two marine terminals, the Tenth Avenue Marine Terminal (TAMT) and the National City Marine Terminal (NCMT) are located adjacent to Barrio Logan and are the most important local generators of diesel truck traffic. Specific community concerns have focused on diesel truck impacts including air pollution, noise, and decreased pedestrian safety resulting from both through traffic and parked/idling vehicles on local streets in Barrio Logan generated primarily by the TAMT.

This study (Karner et al., 2008) focused on the sequentially implemented mitigation efforts that involved truck rerouting. To estimate the air quality effects of the mitigation measures, DPM emissions were estimated associated with different implementation stages. By matching traffic activity with speed-dependent emissions factors, 24-hour DPM emissions for each of the key streets in the study area were developed. The mitigation measures significantly improved local air quality in the primary affected corridor, resulting in an 87% reduction in diesel truck vehicle miles traveled and a 99% reduction in DPM emissions. However, total DPM emissions on all study links grew by 90% between the baseline and the final rerouting because of the increased rerouted truck travel distance.

This case study suggested that, depending upon local conditions, diesel truck impacts on sensitive communities may be mitigated by rerouting, even when new infrastructure is not employed. The Barrio Logan case demonstrated that localized mitigation measures need not compromise transport operational efficiency. However, the case also illustrated that there can be tradeoffs between localized pollutant reductions and regional-scale emissions. Further research is needed to address the coordination among localized and regional-scale mitigation measures.

Practical Mitigation for Diesel Particulate Matter: Impact of Near-road Vegetation Barriers

Several studies have recently examined how near-road barriers such as sound walls affect air quality near roadways. Some literature, for example, has found that sound walls may intercept plume dispersion and reduce near-field concentrations downwind of the wall (Pierce and Isakov, 2006; Bowker et al., 2007; Clawson et al., 2009). Existing literature supports the idea that there are likely to be pollution reduction benefits associated with planting trees between high volume roads and sensitive land uses. In addition, implementation of tree plantings has the ability to mitigate roadway noise and improve visual aesthetics for near-road communities, and can utilize existing infrastructure employed by state departments of transportation and other agencies charged with maintaining existing landscaping. This research assessed the benefits of vegetation screens near roadways; it was motivated by both the potential for vegetation to reduction pollution and the ability to leverage existing Caltrans standard operation procedures (e.g., landscaping enhancements along freeways).

Based on near-road dispersion principles and some limited real-world observational data, the literature indicates that near-road tree planting has the potential to significantly affect near-road pollutant concentrations. In some situations, for example, vegetation may have a similar effect as a sound wall on wind flows. Trees can create a buffer zone between the pollutant source and receptors near roadways, intercept plume dispersion, and remove gaseous pollutants by stomata uptake or sticky surfaces. The effectiveness of PM removal via tree plantings may increase if the species chosen have rough and sticky surfaces, consist of a fine, complex foliage structure that allows significant in-canopy airflow, retain foliage throughout the year, have a long life span, and have a low biogenic volatile organic compound emission rate. The impact of trees on pollutant removal may also vary by particulate size ranges. While plantings that maximize surface area and provide stickier surfaces increase coarse PM capture, plantings that have greater surface area and allow for significant in-canopy airflow are more efficient scavengers of fine and ultra fine PM due to the turbulence created by the complex foliage structure.

To illustrate how the literature findings might apply to real-world situations, we conducted a case study using the Willett Elementary School site located near a freeway in Davis, California; the case study quantified the potential PM removal from vegetative planting between the road and the school (Fuller et al., 2009). A data screening process was first employed to determine suitable vegetation species for the study plot, based on the species selector component of peer-reviewed software (called *i-Tree*) and California's guidance for irrigation water needs of landscape plantings. A conceptual dry deposition model was then developed and used to estimate the amount of PM removed by the near-road vegetation, considering pollutant flux, concentration, dry deposition rate, leaf area index, tree height, and other factors. The case study showed that vegetation at the Willett Elementary School plot could be expected to remove about $0.04 \mu\text{g}/\text{m}^3$ per second or 121 kg/year of PM, which represented an estimated PM concentration reduction of approximately 4.6 percent per hour given the assumed mixing height and area. Leaf area index and dry deposition rate were key model parameters for modeling PM removal.

To accurately analyze pollutant transport, deposition, and removal in a variety of near-road planting configurations, more detailed modeling and further research are needed, especially with respect to horizontal perspective models and key assumptions for leaf surface area and percent coverage.

Conclusions and Future Research

The five studies included in this research with respect to air quality mitigation measures aimed to identify potential mitigation opportunities and speed project delivery by proactively addressing project-level environmental concerns. Mitigation measures can reduce vehicular emissions directly, or indirectly. Prior studies showed general consensus on the correlation between operational parameters and vehicular emissions, and suggested that smoothing traffic and reducing engine load would be typical ways to reduce diesel PM emissions. Minimizing the air pollutant concentration for receptors within the first 150-400m from a roadway would be particularly beneficial for addressing near-road air pollution issues. Among the wide range of potential mitigation measures, TSM measures appeared to have good potential benefits as project-level diesel control measures. Goods movement-related mitigation approaches such as truck rerouting may reduce local diesel impacts, but may not result in regional air quality benefits. Properly developed vegetation screens may be a useful measure to reduce impacts of freeway operations on near-road air quality.

Further research is needed to improve understanding of mitigation measures and their implementation including, but not limited to, further vehicle tests to identify important parameters associated with diesel truck emissions, detailed assessment of mitigation measures from both regional and project perspectives, further evaluation of vegetative screens, and development of modeling tools to estimate potential mitigation effects. In addition, the meta-analysis of observed near-road pollution concentrations can be further extended to investigate the effectiveness of mitigation strategies for various pollutants, as a function of distance from roads.

References

Bowkera, G. E., Baldauf, R., Isakov, V., Khlystov, A., and Petersen, W. (2007). The Effects of Roadside Structures on the Transport and Dispersion of Ultrafine Particles from Highways. *Atmospheric Environment*, 41, pp. 8128–8139.

California Air Resources Board (2009). The California Almanac of Emissions and Air Quality 2009 Edition. Planning and Technical Support Division, California Air Resources Board. Available at <http://www.arb.ca.gov/Aqd/almanac/almanac.htm>

Clawson, K. L., Eckman, R., Pierce, T., Carter, R., Finn, D., Perry, S., Isakov, V., and Rich, J. (2009). 2008 Roadway Sound Barrier Atmospheric Tracer Study. Presented at the American Meteorological Society 89th Annual Meeting, Phoenix, Arizona, January 10-16, 2009.

Fuller M., Bai S., Eisinger D., Niemeier D. (2009) Practical Mitigation Measures for Diesel Particulate Matter: Near-Road Vegetation Barriers. Report prepared for the California Department of Transportation, Sacramento, CA, by the University of California, Davis-Caltrans Air Quality Project, Davis, CA, July.

Karner A., Eisinger D., Bai S., Niemeier D. (2008) Mitigating Diesel Truck Impacts in Environmental Justice Communities: Transportation Planning and Air Quality in Barrio Logan, San Diego. Report prepared for the California Department of Transportation, Sacramento, CA, by the University of California, Davis-Caltrans Air Quality Project, Davis, CA, November.

Karner A., Eisinger D., Niemeier D. (2009) Near Roadway Air Quality: A Meta-Analysis. Report prepared for the California Department of Transportation, Sacramento, CA, by the University of California, Davis-Caltrans Air Quality Project, Davis, CA, January.

Pierce, T. and Isakov, V. (2006). Near Roadway Research in the Atmospheric Modeling Division. Atmospheric Sciences Modeling Division, U.S. Environmental Protection Agency. Presented at the Coordinating Research Council (CRC) Mobile Source Air Toxics Workshop, Phoenix, Arizona, October 23-25, 2006.

South Coast Air Quality Management District (2008). Multiple Air Toxics Exposure Study in the South Coast Air Basin: Final Report. Diamond Bar, CA, September 2008. Available at <http://www.aqmd.gov/prdas/matesIII/MATESIIIFinalReportSept2008.html>

Van Houtte, J., Eisinger D., Niemeier D. (2008) Project-Level Mitigation: What Affects Diesel Particulate Matter Emissions. Report prepared for the California Department of Transportation, Sacramento, CA, by the University of California, Davis-Caltrans Air Quality Project, Davis, CA, November.

Yura, E.A., Eisinger D., Niemeier D. (2006) A Review of On-Road Vehicle, Mitigation Measures. Report prepared for the California Department of Transportation, Sacramento, CA, by the University of California, Davis-Caltrans Air Quality Project, Davis, CA, September.